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# A MARINE GEOTECHNIQUE STUDY UTILIZING A SUBMERSIBLE. A PROGRESS REPORT ON THE GEOMECHANICAL STUDY OF THE SEA FLOOR INDEPENDENT RESEARCH PROGRAM

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NOVEMBER 1969


PREPARED BY

LOCKHEED OCEAN LABORATORY

OCEAN SYSTEMS

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A DIVISION OF LOCKHEED AIRCRAFT CORPORATION





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## PREFACE

The following text is a report of the progress made on the Geomechanical Study of the Sea Floor Independent Research Program through October 31, 1969. Funding limitations prohibited additional DR/V DEEP QUEST dives on this program until late 1969. Because of these dives occurring so late in the year, completion of the data analyses and topographical effects phase of the overall program will be carried into the Independent Research program of 1970.

All data presented in this report are based upon the two DEEP QUEST dives of April 1 and 2, 1969, and the seven cores obtained during those two dives. Because of the paucity of data, no real conclusions can be drawn at this time, only trends indicated. It is hoped that the November 1969 dives of DR/V DEEP QUEST will substantiate the trends suggested by the work presented in this report.

## ABSTRACT

A brief bathymetric survey was performed and seven cores obtained along two precise sampling transects by the submersible DR/V DEEP QUEST. This work was performed along a gullied section of the upper San Diego Trough slope off Del Mar, California. Purpose of the study was to investigate the topographical effects on mass physical properties of marine sediments as well as gain more information concerning the stability of underwater slopes and lateral variability of sediment properties. The cores were obtained along transects across a gully at right angles to the axis and down an interfluvial slope approximately parallel to the gully axis. Sediments within the cores were tested for shear strength, water content, bulk density, grain size distribution and Atterberg limits. Related parameters were computed from the test results.

Although the data are too limited for definite conclusions, certain relationships were indicated. A surficial layer of silty clay is apparent over most of the sampled area. Within this material the following topographical relationships are indicated. In traversing the gully from the lip toward the center, the amount of clay, liquid and plastic limits, and water content increase while the bulk density and rate of water content reduction with core depth decrease. No apparent relationships between topography and sediment properties are indicated for the material obtained along the interfluvial slope. Water content values appear to remain relatively constant below a certain depth in all cores but one. With the exception of the surficial silty clay layer, there does not appear to be any relationship between water content and topography. Nor is any relationship between shear strength and topography indicated. A non-linear increase in shear strength is indicated for at least

three of the cores. All of the materials encountered within the cores appear stable at their existing slope angles.

This project has demonstrated the great value of DR/V DEEP QUEST as a research tool. Without the submersible, the precision coring and detailed bathymetric work would have been impossible.

## INTRODUCTION

Primary objective of this study is to investigate the topographical effects on the mass physical properties of marine sediments. This type of study can only be accomplished by sampling the sea floor at precise locations along specific tracks. This accomplishment has been made possible by the use of Lockheed's research submersible, DR/V DEEP QUEST. Secondary objectives of the program are to gain more information on the relationship between the stability of underwater slopes and mass physical properties of sediments as well as to gain more knowledge concerning the lateral variability of marine sediments.

Two dives were made by DR/V DEEP QUEST along the upper slope of the San Diego Trough off Del Mar, California. Using DEEP QUEST and its unique coring device, it was possible to select the desired location for coring and to take a series of cores along precise transects. Two coring tracks were made in which seven cores of recent marine sediments were obtained. The first set of cores was taken across a selected gully perpendicular to its axis. The second set of cores was taken downslope approximately parallel to the axis of the gully. A brief bottom survey was also made of the area, utilizing the echo sounder aboard the submersible in order to compare contours with previously derived data from a surface ship survey (Inderbitzen, 1965).

Laboratory analyses primarily focused on investigating the mass physical properties of the sediments collected. Shear strength of the sediments was determined by direct shear, vane shear and unconfined compression tests.

Other tests included determination of water content, bulk density, grain size distribution and Atterberg limits. Liquidity index, activity ratio and other related sediment parameters were also computed. All data were studied for possible trends that could be related to the observed topography. Stability analyses also were performed for the slopes within the sampling area.

Until recently, investigations of the geomechanic properties of the sea floor have been greatly hampered by the inherent limitations of working from a surface ship. Results and predictions concerning the properties of marine sediments and their expected behavior in a number of circumstances are based primarily on laboratory tests of sediment samples. Limitations of this approach have prevented the investigator from determining the relationship of his results to the complex sea floor topography. These limitations include: 1) errors in accurately mapping the bottom topography, 2) inability to control the exact location where a sample is to be taken, 3) statistical problems of determining whether a sample taken is truly representative of the surrounding sediments or not. Solutions to these problems can now be obtained with the aid of the working submersible. Furthermore, many other existing marine geological and geophysical problems can now be investigated more thoroughly and with greater accuracy.

Although the working submersible holds great promise for geological and geophysical research, to date the number of studies conducted utilizing it are relatively few. This is attributed to the novelty of working submersibles, their high operating costs and their rather undefined role in oceanographic research. Another factor influencing their limited utilization has been lack of suitable geological and geophysical instrumentation for use from a submersible. Busby and Costin (1968) have made a comprehensive evaluation

of the submersible as a research tool. Their findings indicate the existence of a wide range of surveying missions and research tasks that would greatly benefit from its use. Among the areas of work for the submersible cited by Busby and Costin are site surveys, bottom truth surveys, route selection surveys and biological and geological surveys.

To the present date, the majority of geologic research undertaken utilizing a submersible has been observational only. Moore (1963, 1965) made some geologic observations of the topography and bottom processes along the La Jolla sea-fan valley and near the edge of the continental shelf off San Diego, California, from the bathyscaph TRIESTE. Shepard (1965, 1967) and others (Shepard et al., 1964), have extensively explored some of the submarine canyons off the coast of California using Costeau's diving saucer and the TRIESTE. Hawkins (1968) visually investigated the manganese deposits on the Blake Plateau from the DEEPSTAR-4000. Other geologic and biologic observational studies have been made from the submersibles ALVIN and DEEPSTAR-4000. Results from many of these studies are still pending publication.

Numerous geological studies have also been made involving measurements or sediment sample collection from a submersible. Hamilton (1963) carried out in-situ measurements of sediment sound velocity from the bathyscaph TRIESTE. Buffington, Moore and Hamilton (1967) made in-situ measurements of bottom slopes, sediment sound velocity and sediment shear strength from the DEEPSTAR-4000. Milliam and others (1967) made in-situ sediment resistivity measurements from the ALVIN. Other parameters often measured in most of these studies include water temperature and bottom currents.

## DESCRIPTION OF THE AREA

The location of the area surveyed is approximately 3 km west of Del Mar, California, between latitudes 32° 57' N and 32° 59' N and longitudes 117° 18'W and 117° 20'W (Figure 1). The complex topography of this area with its numerous gullies and relatively steep slopes (Inderbitzen, 1965) made it an ideal site for this type of study.

Navigational control for the detailed survey of the selected area was accomplished by the CTF scanning sonar on DEEP QUEST in conjunction with a fixed transponder on the sea floor. Location of the transponder was determined from observations of the horizontal sextant angles between three known triangulation stations on the shore. Accurate bottom contours of the area were obtained by an echo sounder aboard the submersible. The angles of bottom slopes and gully axes were measured by setting the submersible gently on the bottom and measuring the inclination angle of the submersible.

Figure 2 presents two bathymetric charts, one was generated by a surface survey (Inderbitzen, 1965) and the other was obtained from DEEP QUEST's surveys. It should be noted how much greater detail was obtained on the submersible survey. Most of the small gullies observed by DEEP QUEST were undetected by the echo sounder of the surface ship. Similar results are reported by Busby and Costin (1968) for other studies where a submersible was used to verify or add to the data obtained by a surface survey.

The gully selected for coring is approximately 60 meters wide with a relief of about 15 meters between the edges and its center. The axis of the

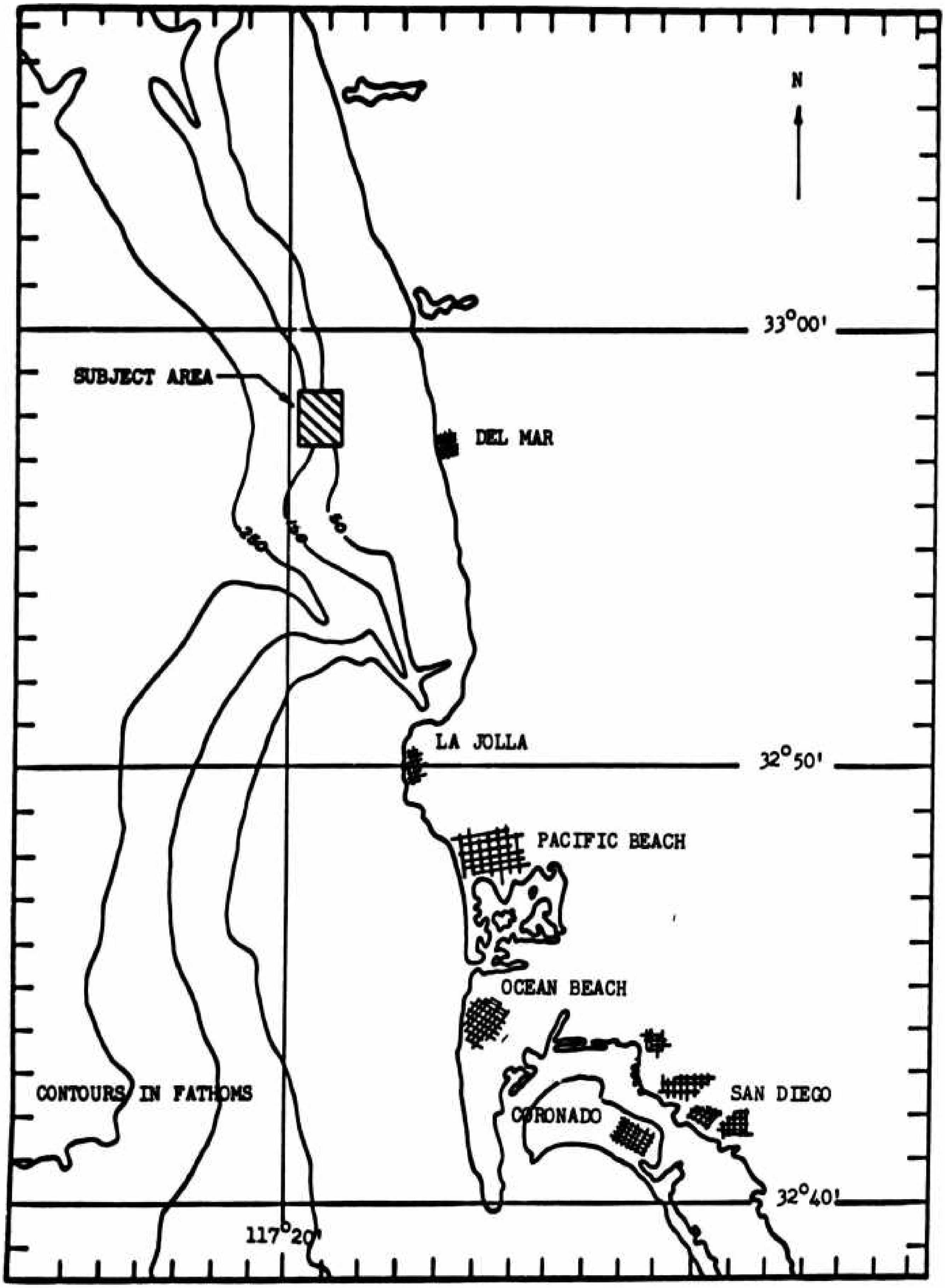
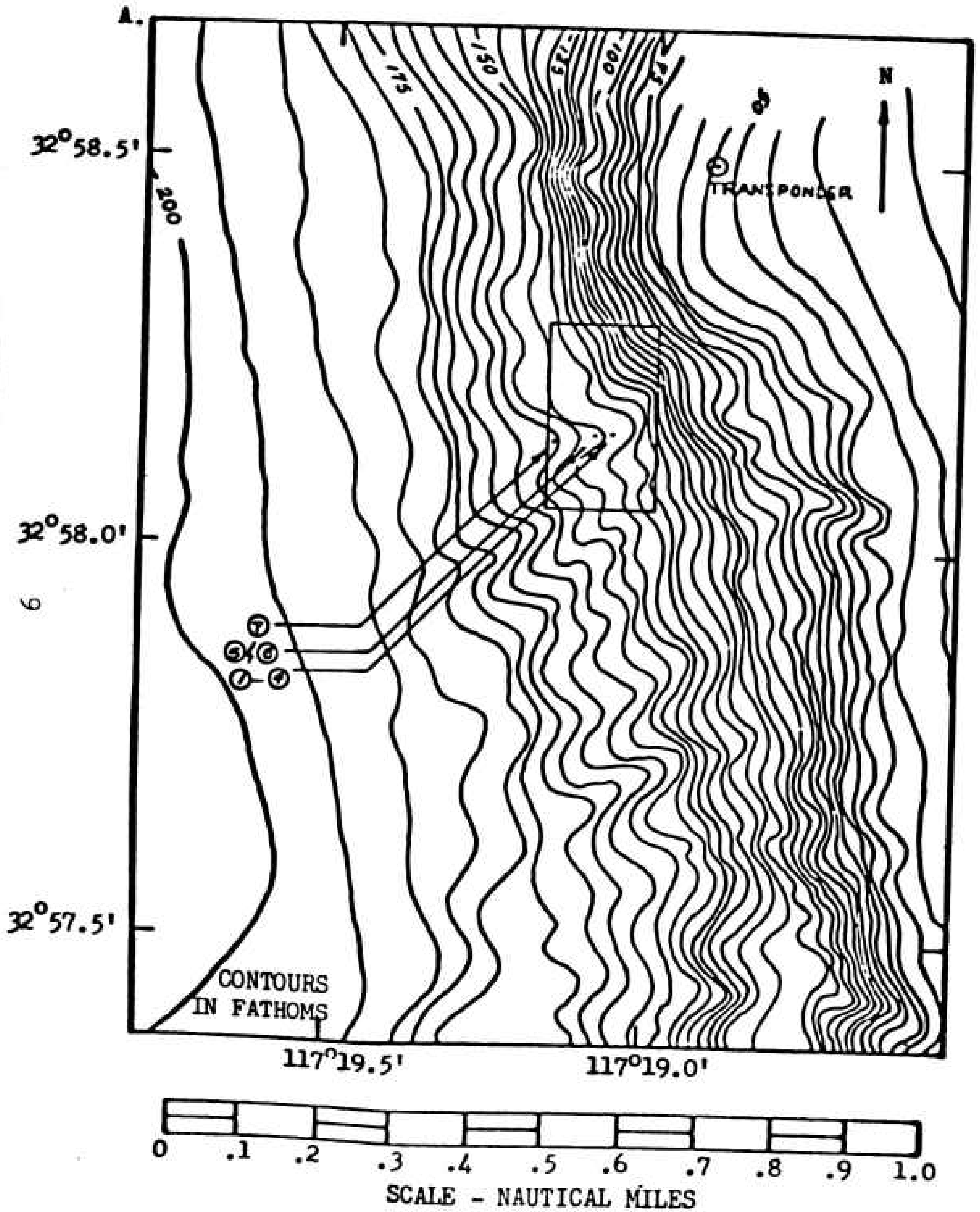
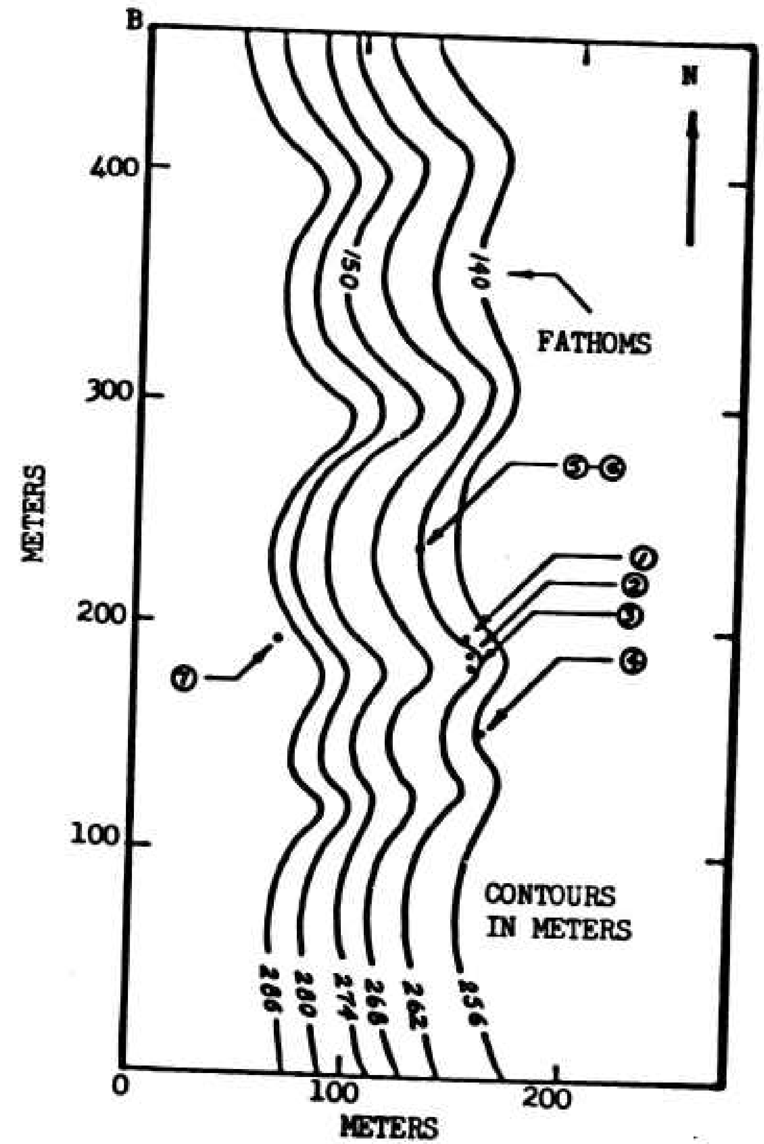



FIGURE 1. LOCATION OF THE SUBJECT AREA.




ENLARGED CHART OF SECTION
SURVEYED BY DEEP QUEST

FIGURE 2. SUBMARINE TOPOGRAPHY AND CORE LOCATIONS WITHIN THE SUBJECT AREA. BATHYMETRIC CONTOURS IN (A) BASED UPON SURFACE SURVEY (INDERBITZEN, 1965) AND IN (B) BASED UPON SUBSURFACE SURVEY BY DEEP QUEST.

gully plunges almost directly west with an average slope of about 21 degrees. Side slopes of the gully range from 7 to 16 degrees. Observed variations in the axis angle through the length of the gully (approximately 300 meters) range from as low as 14 degrees to as high as 34 degrees. These axial slope angles are approximately the same as the axial slope angles originally measured from the surface ship survey of 1965. The declivity of the interfluvial slopes, within the area shown by figure 2b, ranges from 18 to 20 degrees and averages about 18.5 degrees. Figure 3 illustrates cross-sections of both the gully and interfluvial slope along the two coring transects.

During coring operations, samples of sea water were collected for salinity analyses. Salinity values ranged from 34.252 to 34.263 parts per thousand. The salinity data were used in the sediment density calculations.

Bottom currents in the study area were visually observed while DR/V DEEP QUEST remained motionless on the sea floor. Based on particle movements past the viewports, the speed of the bottom currents was estimated to be negligible. In all cases the speeds were well below 15 cm/sec (.3 knot).

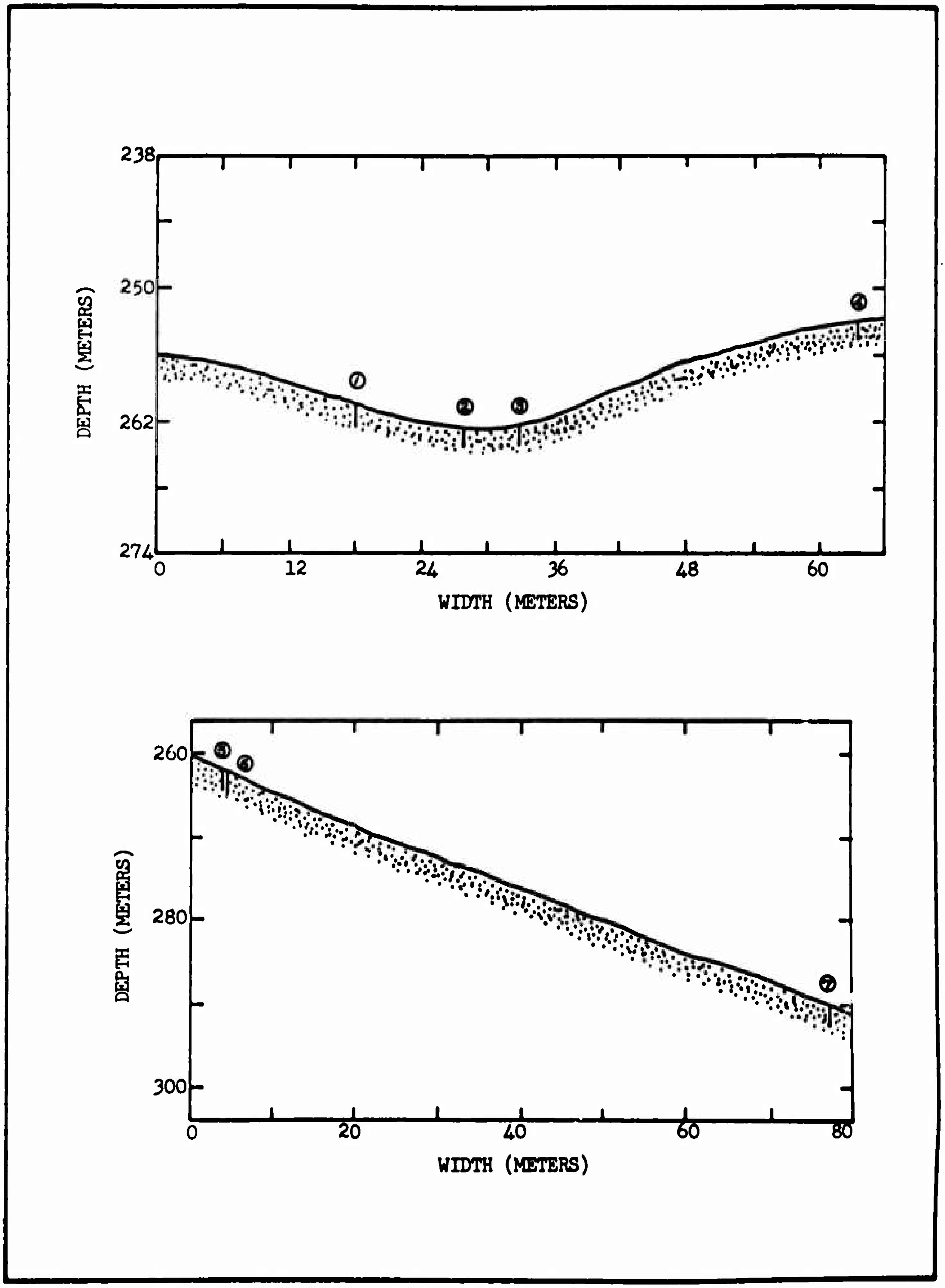



FIGURE 3. RELATIONSHIPS BETWEEN CORE LOCATIONS AND BOTTOM TOPOGRAPHY.

## STUDY PROCEDURES

### Sea Phase

On the first dive a general reconnaisance of the area was made and an appropriate gully selected for coring. Four cores ranging in lengths from 78.4 to 120.4 cm were taken along a transect perpendicular to the axis of the gully. Water depth at the coring sites varied from 253 to 262 meters. Figure 3a presents a cross-section of the gully traversed and the relative location of the cores taken. Although it was intended to take six cores, only four were obtained due to equipment malfunctions.

On the second dive three cores were taken down an interfluvial slope somewhat parallel to the axis of the first gully (Figures 2 and 3b). Cores 5, 6 and 7 were recovered in water depths of 262 to 291 meters and their lengths ranged from 68.4 to 89.4 cm. Cores 5 and 6 were taken within a very close distance of each other to obtain some idea of the lateral variability of mass physical properties with the sediment.

The seven cores collected were obtained using a coring device specifically designed for DR/V DEEP QUEST. This coring device is hydraulically operated and is capable of taking six cores per dive with a minimum of disturbance to the sediments. Length of the clear plastic (cellulose-acetate-butyrate) core barrels is 138.7 cm with an inner diameter of 6.7 and an outer of 7.3 cm. In order to prevent any water loss from the cores during transport and storage, both ends of the barrel were sealed and the entire core barrel encased in a polyethylene sleeve.

## Laboratory Phase

A visual presentation of the laboratory testing program is shown by figure 4. This diagram illustrates the sectioning of the seven cores and identifies the particular tests performed on each section. Core sections necessary for laboratory testing were obtained by cutting the plastic barrel, with a hot wire, perpendicular to its longitudinal axis. This method avoids additional disturbance to the sediment due to extrusion from the core barrel. Each core was analyzed for shear strength, water content, bulk density, grain size distribution and Atterberg limits. Based upon these test results, sensitivity, liquidity index, activity ratio and other related parameters were calculated.

Sediment shear strength was determined by vane shear, direct shear and unconfined compression tests throughout each core. Vane shear tests were made approximately every 15 cm throughout the length of each core. Direct shear tests were made on three, 3 cm long, sections taken from each core at depths of about 32 to 42 cm. Each of these three sections was tested under a different normal load in order to determine the strength envelope for the sediment at that core depth. A similar series of direct shear tests were performed on all cores, except 3 and 7, at depths of about 61 to 71 cm. Cores 3 and 7 were too short for a second series of direct shear tests.

A single unconfined compression test was made on all cores but 6 and 7. These two cores were too short. A core section 8-10 cm long was normally used for this test. A description of the testing procedures and equipment used as well as a more detailed discussion on the strength characteristics of sediments as determined by different shear tests is available in Inderbitzen and Simpson (1969).

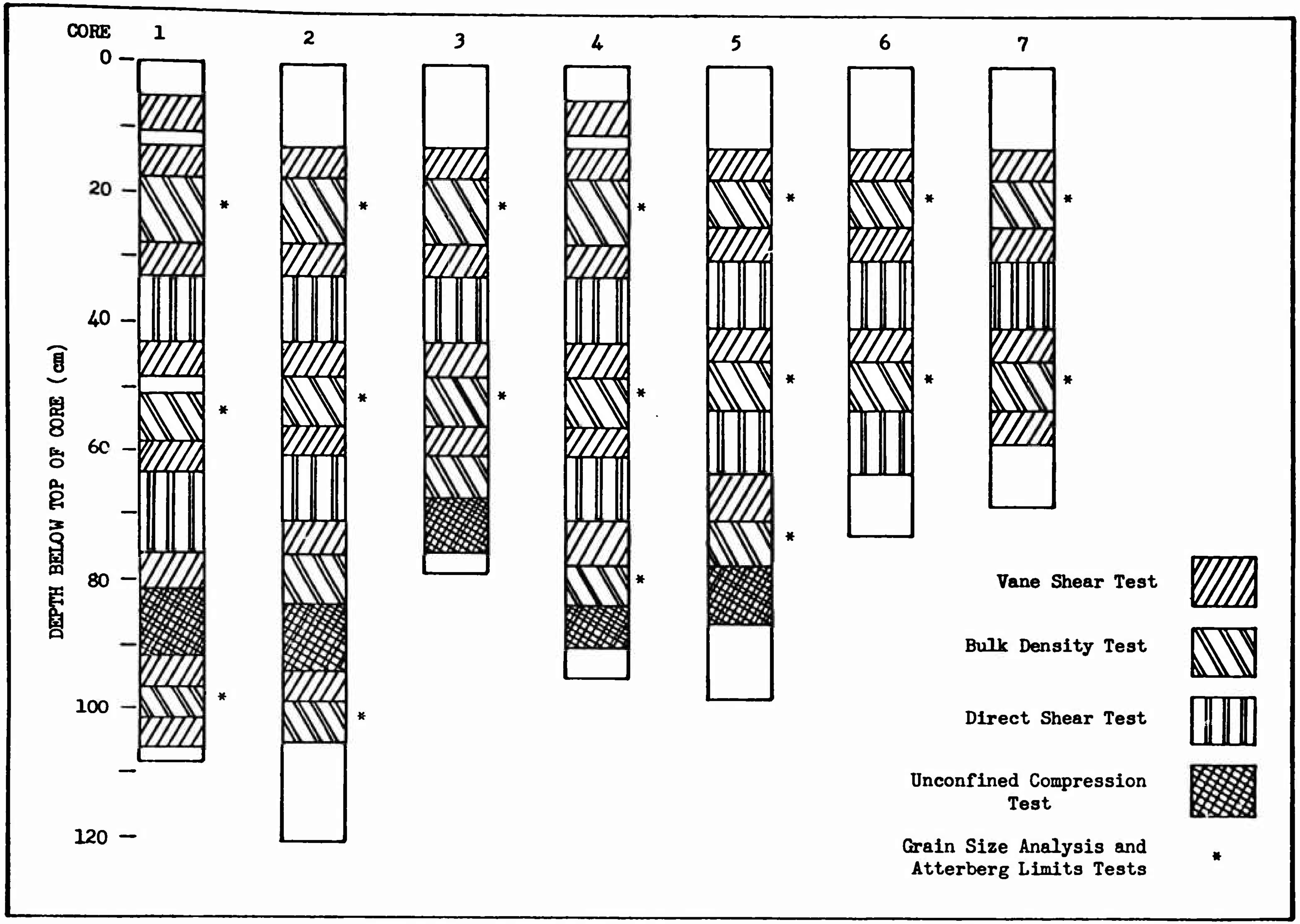



FIGURE 4. LABORATORY TESTS PERFORMED ON EACH CORE.

Bulk density or saturated unit weight of the sediment was determined for at least three samples from each core. These samples were obtained from the top, center and bottom sections of each core. Porosity and void ratios were also computed for each sample (Terzaghi and Peck, 1948). Water content, expressed as percent dry weight, also was determined for all samples used for shear tests as well as those used for unit weight determinations.

At least two Atterberg limit tests were performed on material from each core. These tests were at depths of about 15 and 55 cm. A third Atterberg limits test was performed on cores 1, 2, 4 and 5 at depths shown by figure 4. Tests were performed according to the procedures outlined by the American Society for Testing Materials (anonymous, 1958), except that the entire size fraction was used for the tests rather than just using the material finer than 0.42 mm.

Grain size analyses were performed on all the cores at the same depths that the Atterberg limits tests were performed. A dry sediment sample of approximately 100 grams was used for these tests. Testing procedure used was the same as that in Inderbitzen (1965).

## RESULTS

### Lithologic Units

Figures 5 and 6 demonstrate the lithologic classifications of sediment within each core. The differentiation of sediment types shown by these figures is primarily based upon grain size distribution as well as vane shear and direct shear test results. It is secondarily based upon activity ratio and plasticity index. Nomenclature of the units is based upon the sediment classification system of Shepard (1954).

### Grain Size Distribution

Results of the 18 grain size analyses performed are shown on figures 5 and 6. It appears that all the cores, except number 4, have a very similar grain size distribution and lithological unit in their top 20 to 25 cm regardless of their physiographic location. The cores obtained in this same general area during the 1965 study did not exhibit this characteristic. (Inderbitzen, 1965). Possibly it is due to the fact that the earlier cores were not taken so close together or all in the vicinity of one gully. The similarity in grain size distribution within the top section of the cores suggests that there are uniform transport and depositional processes within the area which are not affected by topographical features. Since this uppermost layer is primarily composed of fine grained material, a low energy environment is suggested.

Lithologic units below the 20 to 25 cm core depth demonstrate some continuity from core to core if the two transects are considered separately

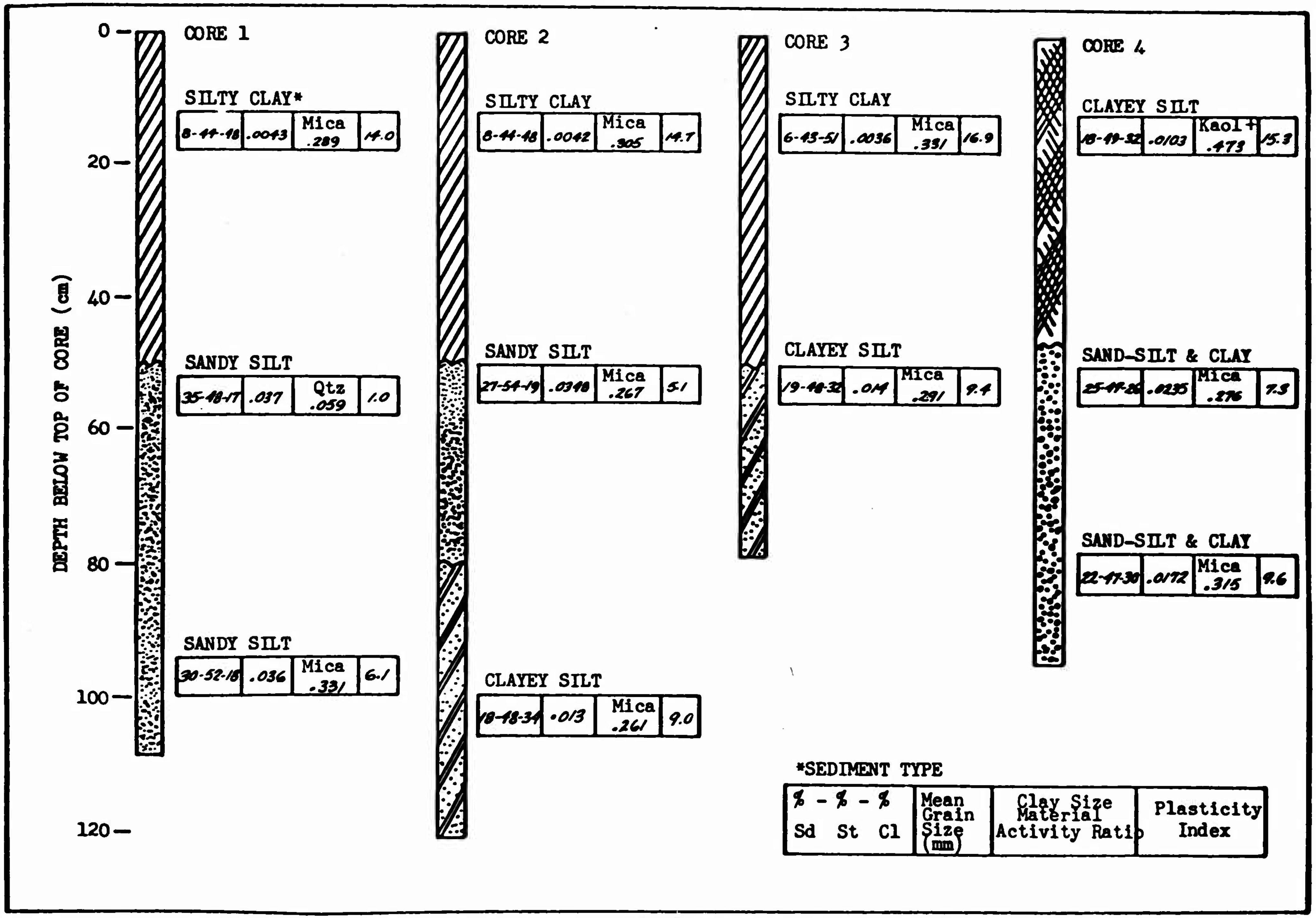



FIGURE 5. SCHEMATIC DIAGRAMS OF THE SEDIMENTS WITHIN CORES 1 THROUGH 4.

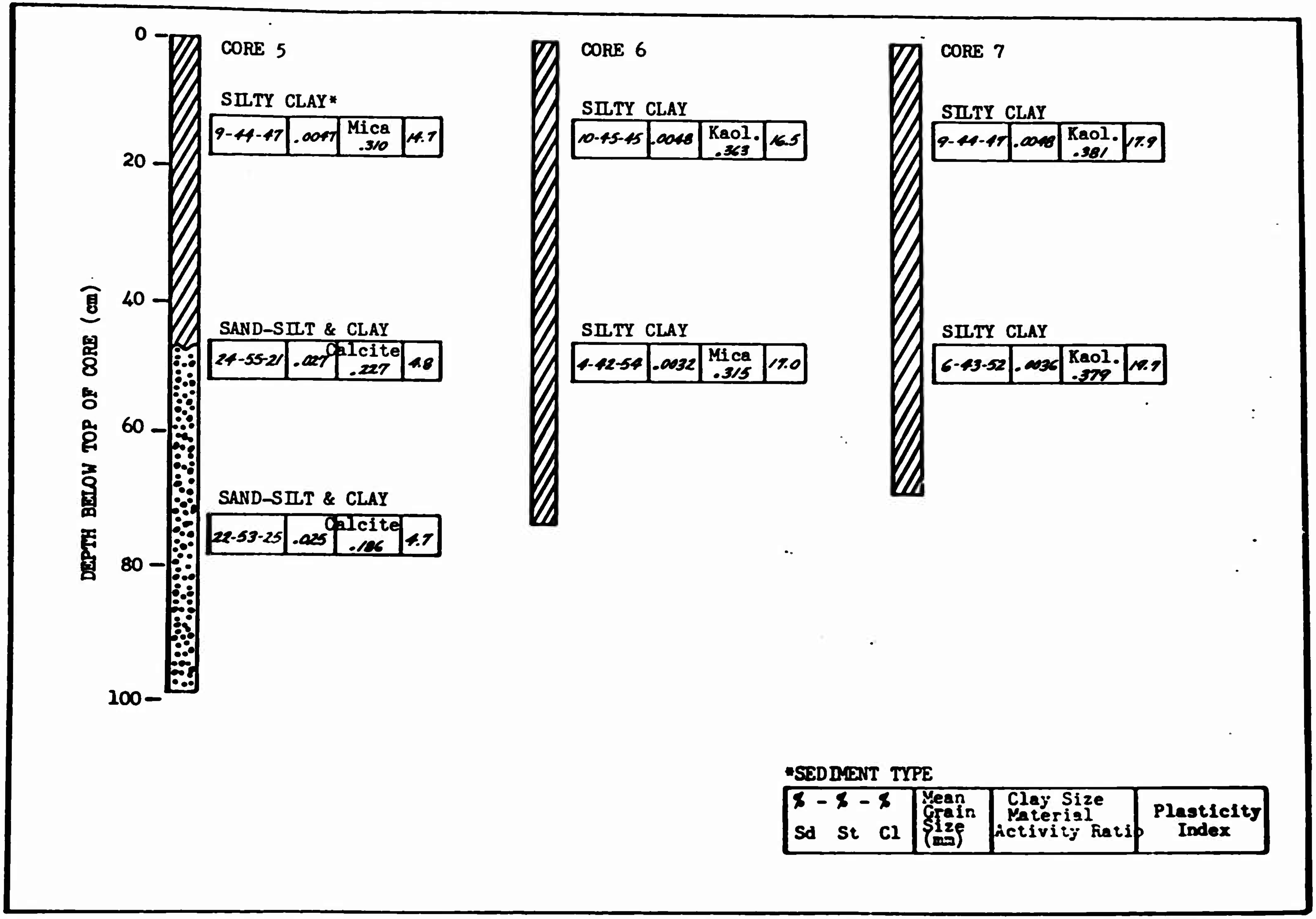



FIGURE 6. SCHEMATIC DIAGRAMS OF THE SEDIMENTS WITHIN CORES 5 THROUGH 7.

(Figs. 7 and 8). Correlation of units across the gully (Fig. 7) suggests that the surficial layer of silty clay was deposited after the gully was formed. The difference in lithologic units encountered in core 4 is believed due to the core's position on the interfluvial slope. Possibly the finer material has been eroded away or was never deposited in this area.

Based upon the grain size distributions of cores 1 through 4 at depths below 20 to 25 cm, the amount of clay-sized material within the sediment increases slightly from the sides of the gully toward the center (see Figs. 5 and 7). A similar trend was observed in the data from the earlier cores (Inderbitzen, 1965).

Of note is the difference in grain size distribution and lithologic units between the lower portions of cores 5 and 6 (Fig. 6). Yet these two cores were taken within a meter of each other. Cores 6 and 7 are quite similar in lithology throughout their entire lengths although they were taken approximately 59 meters apart. It appears that there may be a rapid increase in the thickness of the surficial silty clay unit between cores 5 and 6 (Fig. 8). The high degree of lateral variability in other sediment properties (shear strength, water content and plasticity index) between cores 5 and 6 can be explained by the difference in lithologic units in the lower sections of these two cores.

## Atterberg Limits

Figures 9 through 15 demonstrate the numerical results of tests performed on each core including Atterberg limits (liquid limit, plastic limit and plasticity index). Atterberg limits were determined in each core at the same depths that the grain size analyses were made. Based upon the plasticity chart (a plot of plasticity index versus liquid limit) (Fig. 16), the material

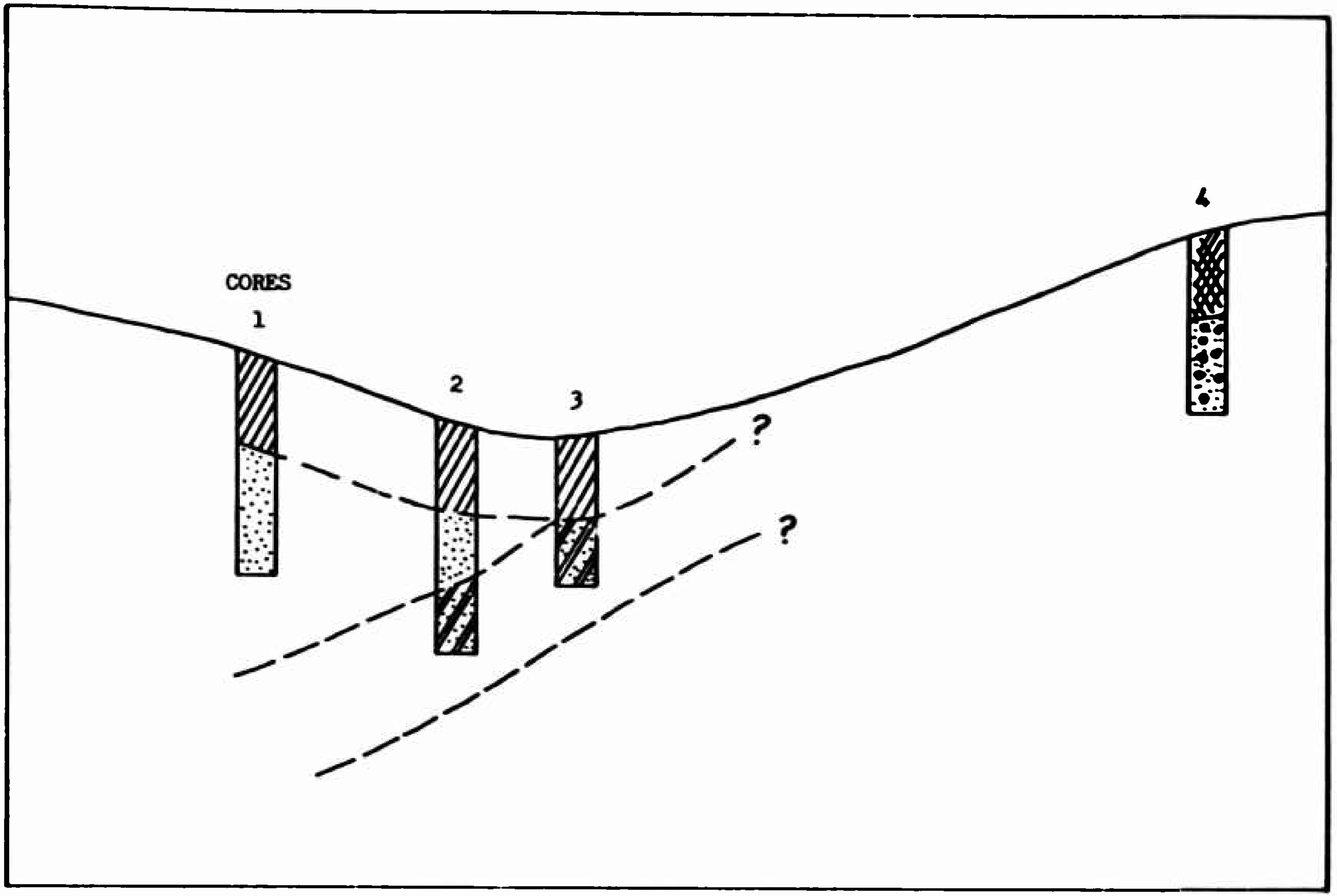



FIGURE 7. DIAGRAMMATIC SKETCH OF MATERIALS IN CORES TAKEN ACROSS THE GULLY.

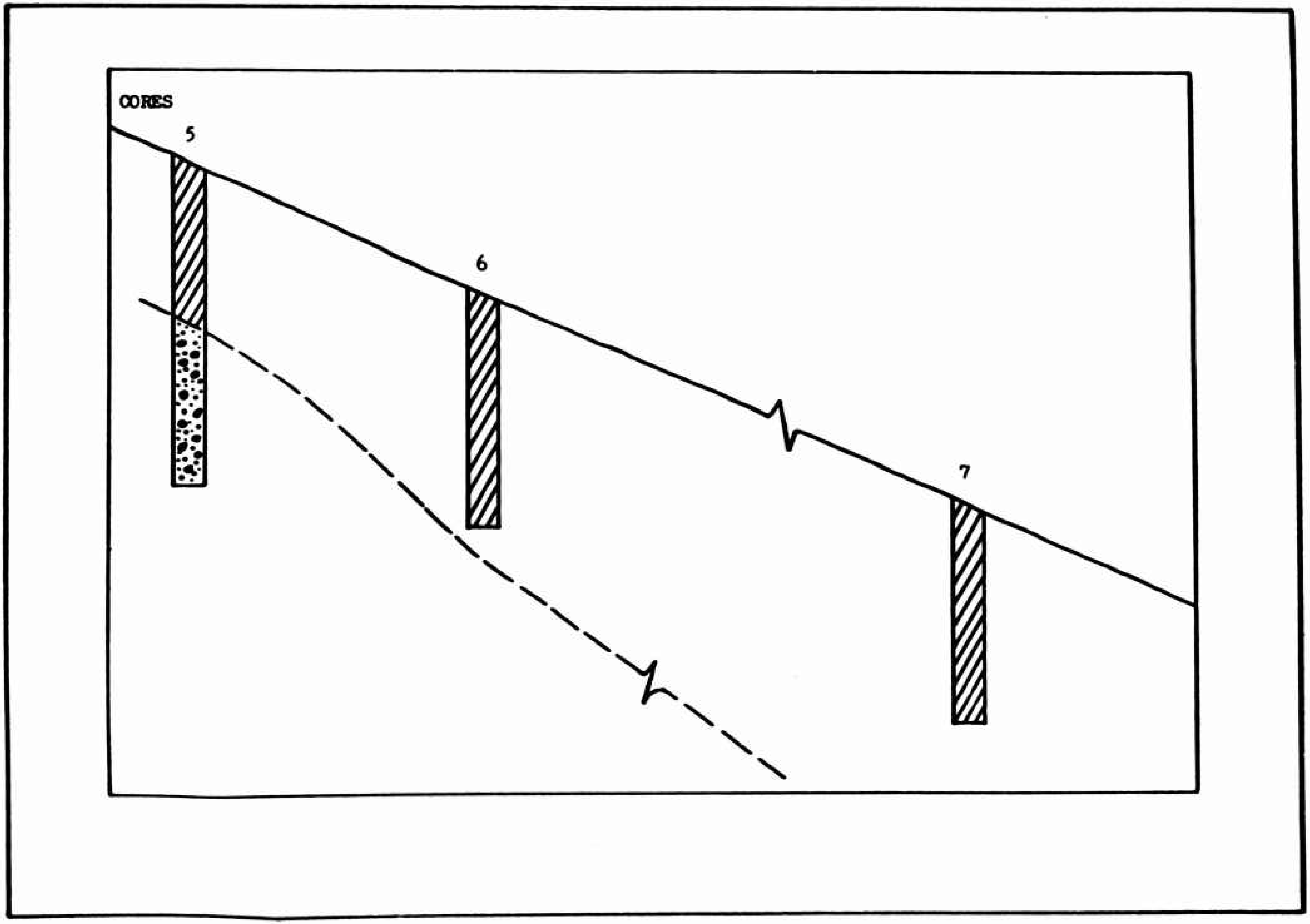


FIGURE 8. DIAGRAMMATIC SKETCH OF MATERIALS IN CORES TAKEN ALONG INTERFLUVIAL SLOPE.

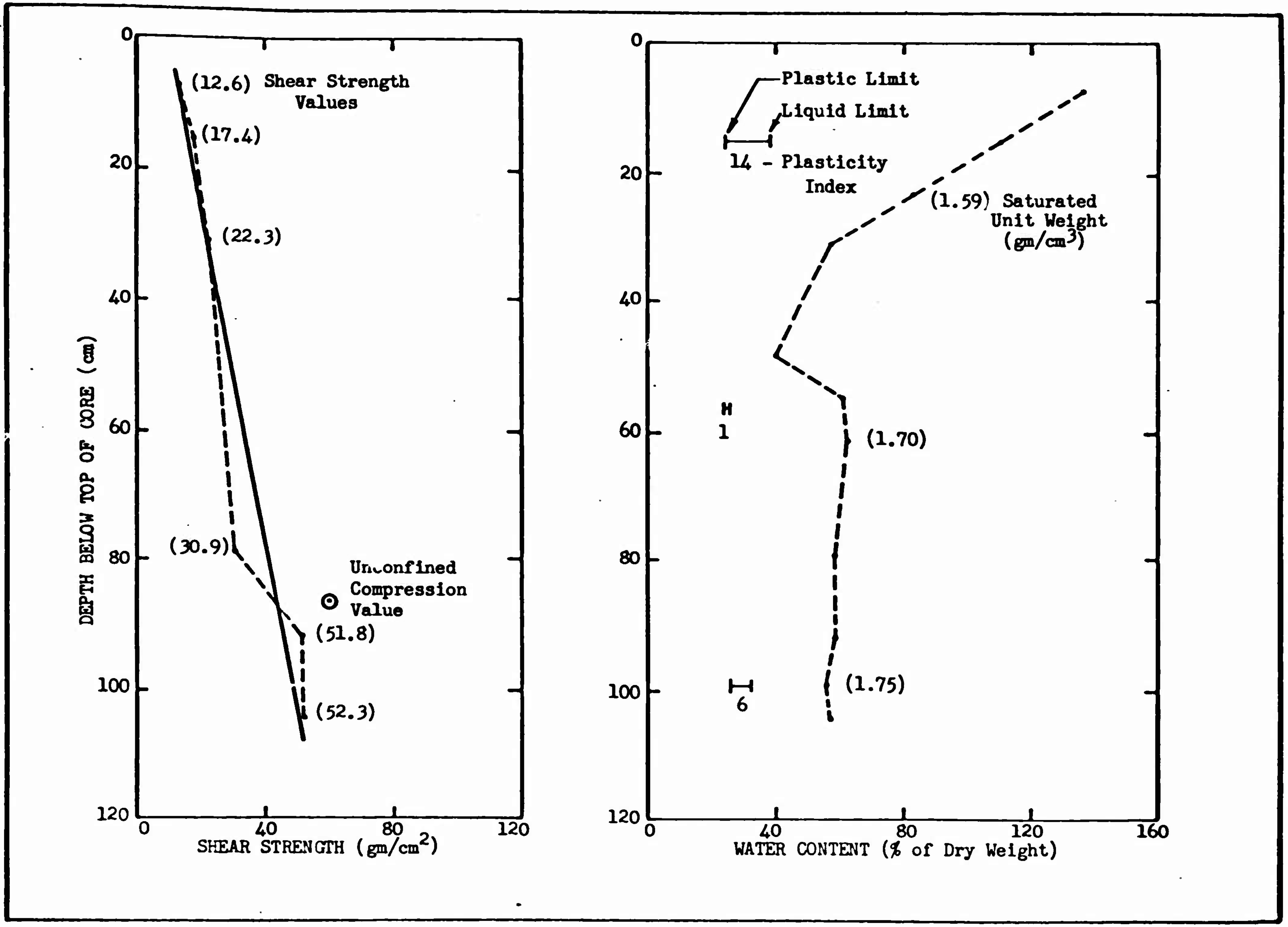



FIGURE 9. MASS PHYSICAL PROPERTIES AS MEASURED IN CORE 1.

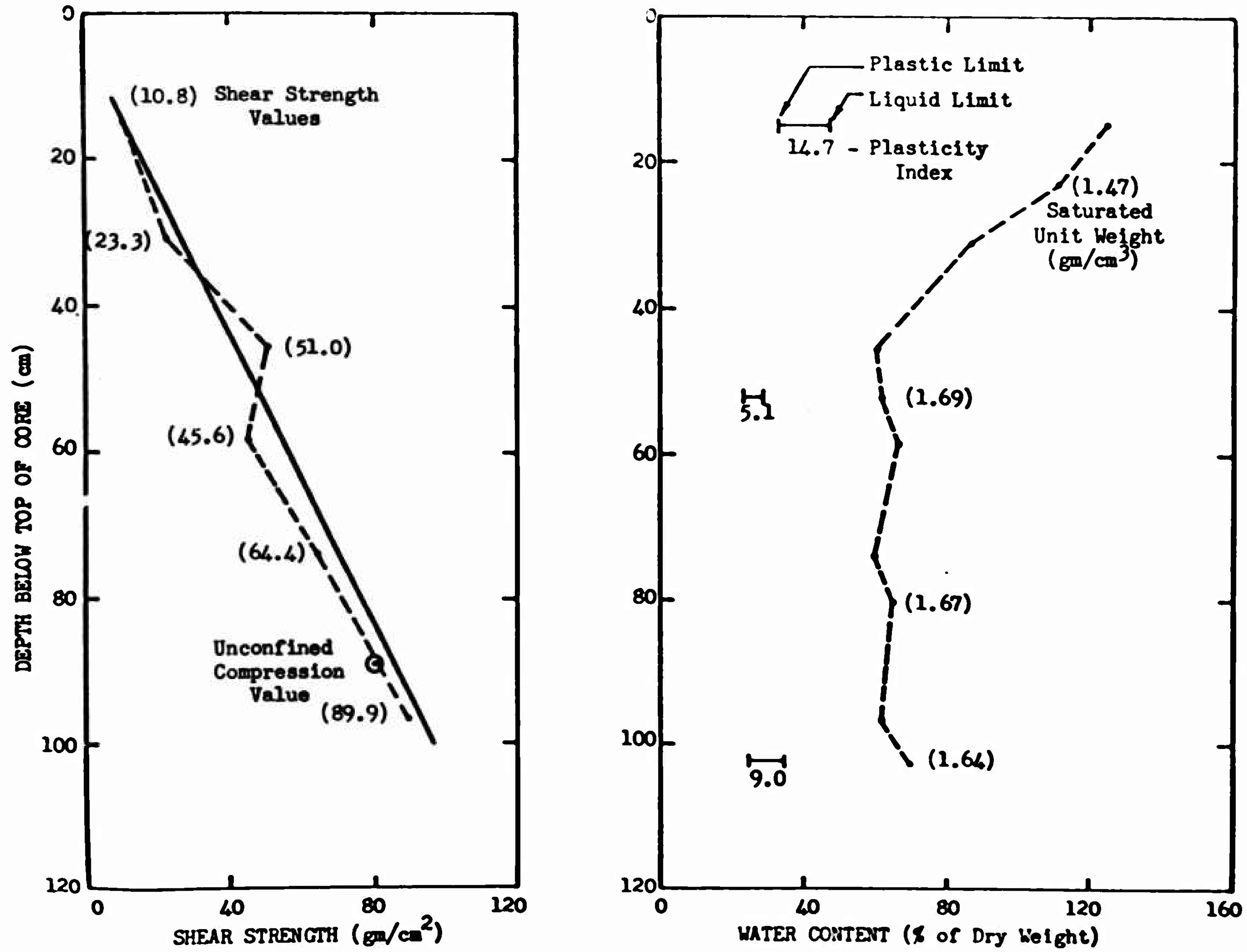



FIGURE 10. MASS PHYSICAL PROPERTIES AS MEASURED IN CORE 2.

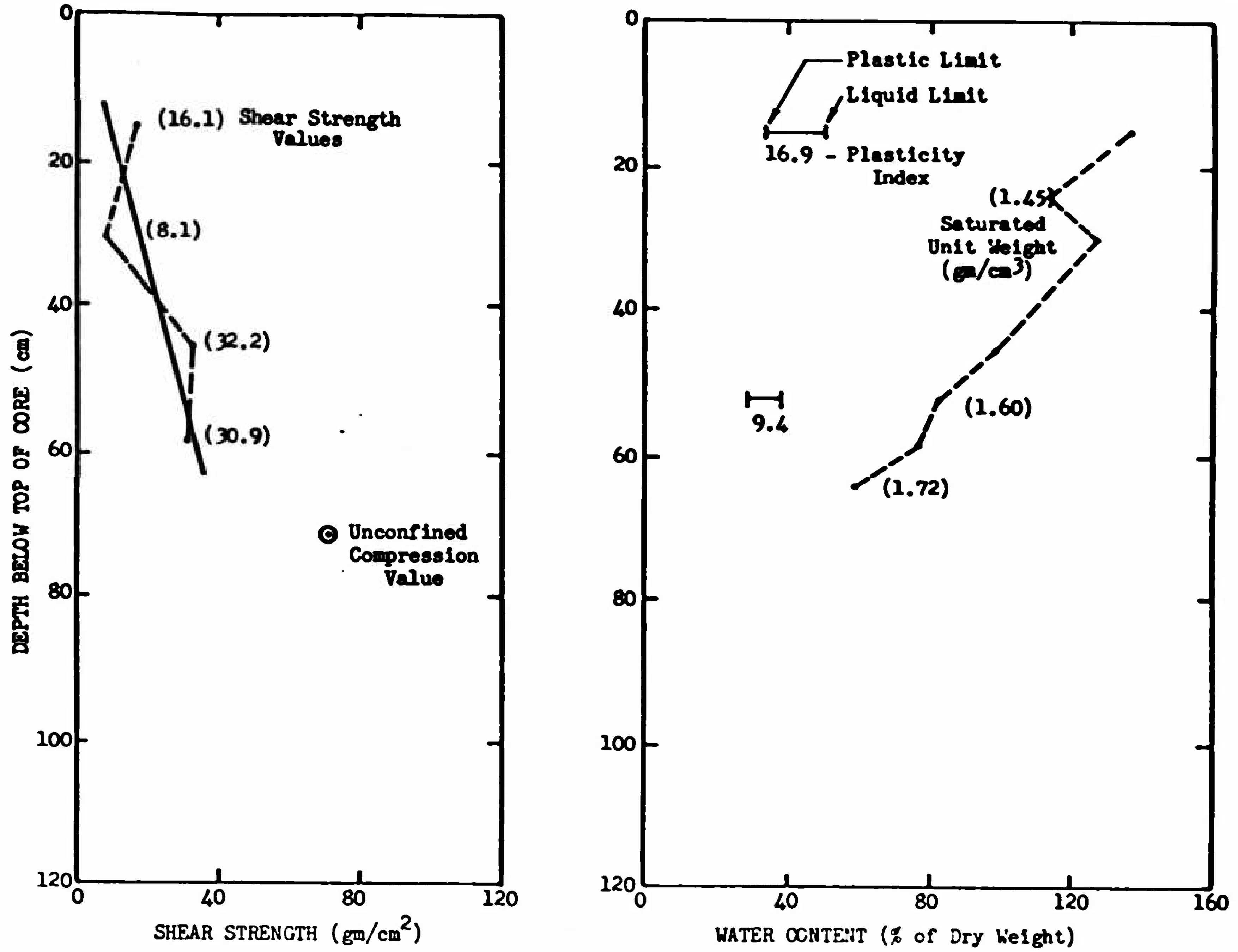



FIGURE 11. MASS PHYSICAL PROPERTIES AS MEASURED IN CORE 3.

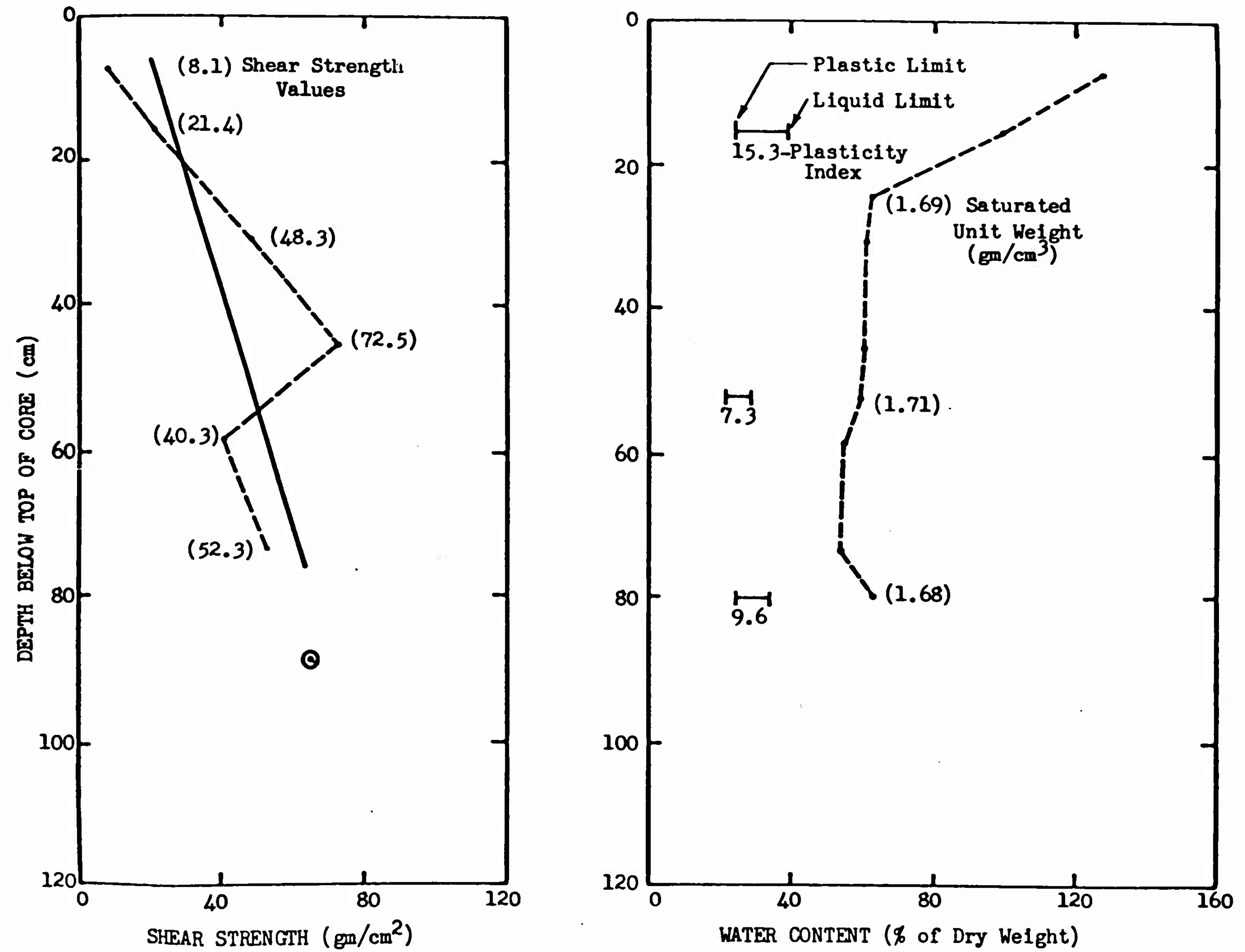



FIGURE 12. MASS PHYSICAL PROPERTIES AS MEASURED IN CORE 4.

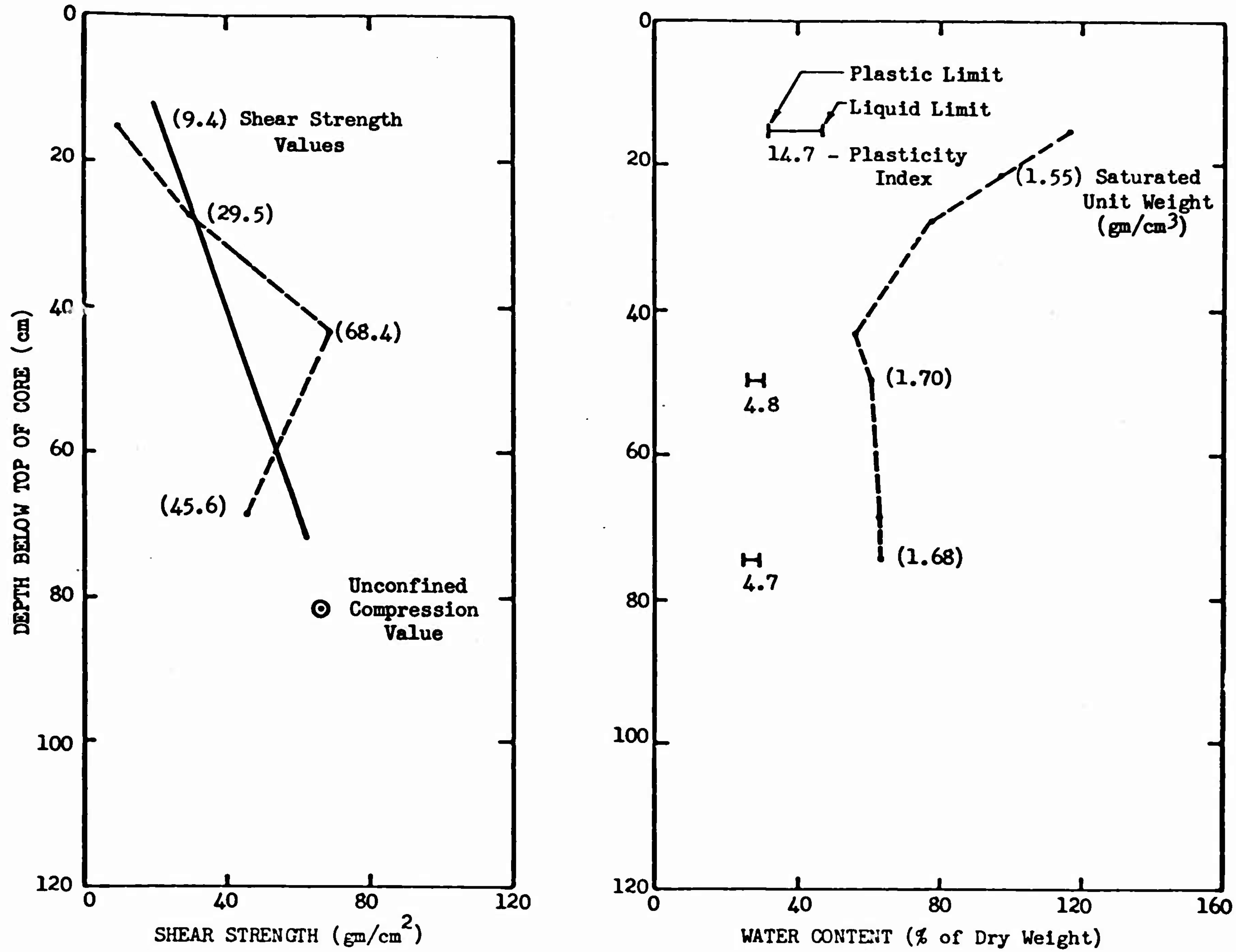



FIGURE 13. MASS PHYSICAL PROPERTIES AS MEASURED IN CORE 5.

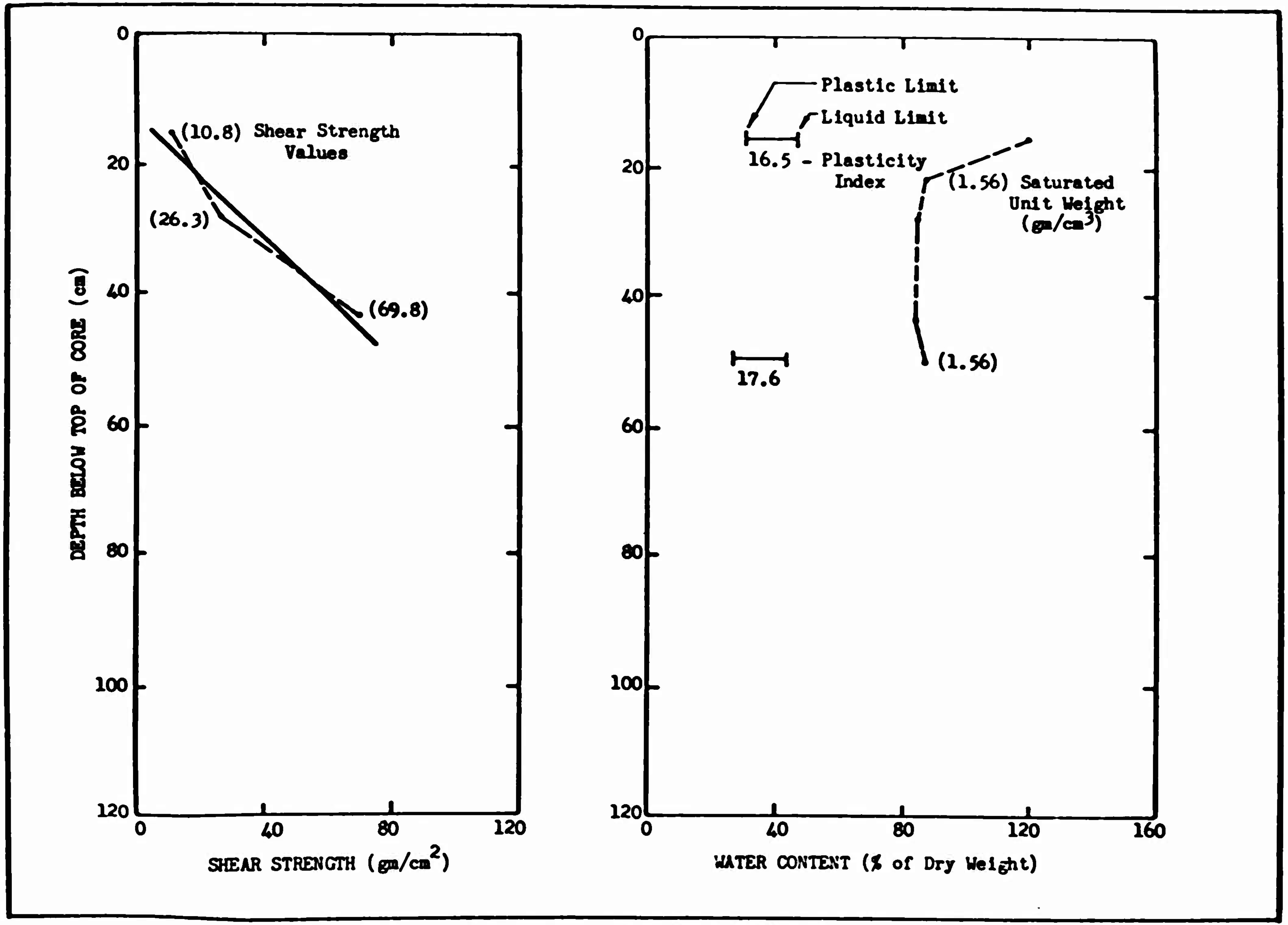



FIGURE 14. MASS PHYSICAL PROPERTIES AS MEASURED IN CORE 6.

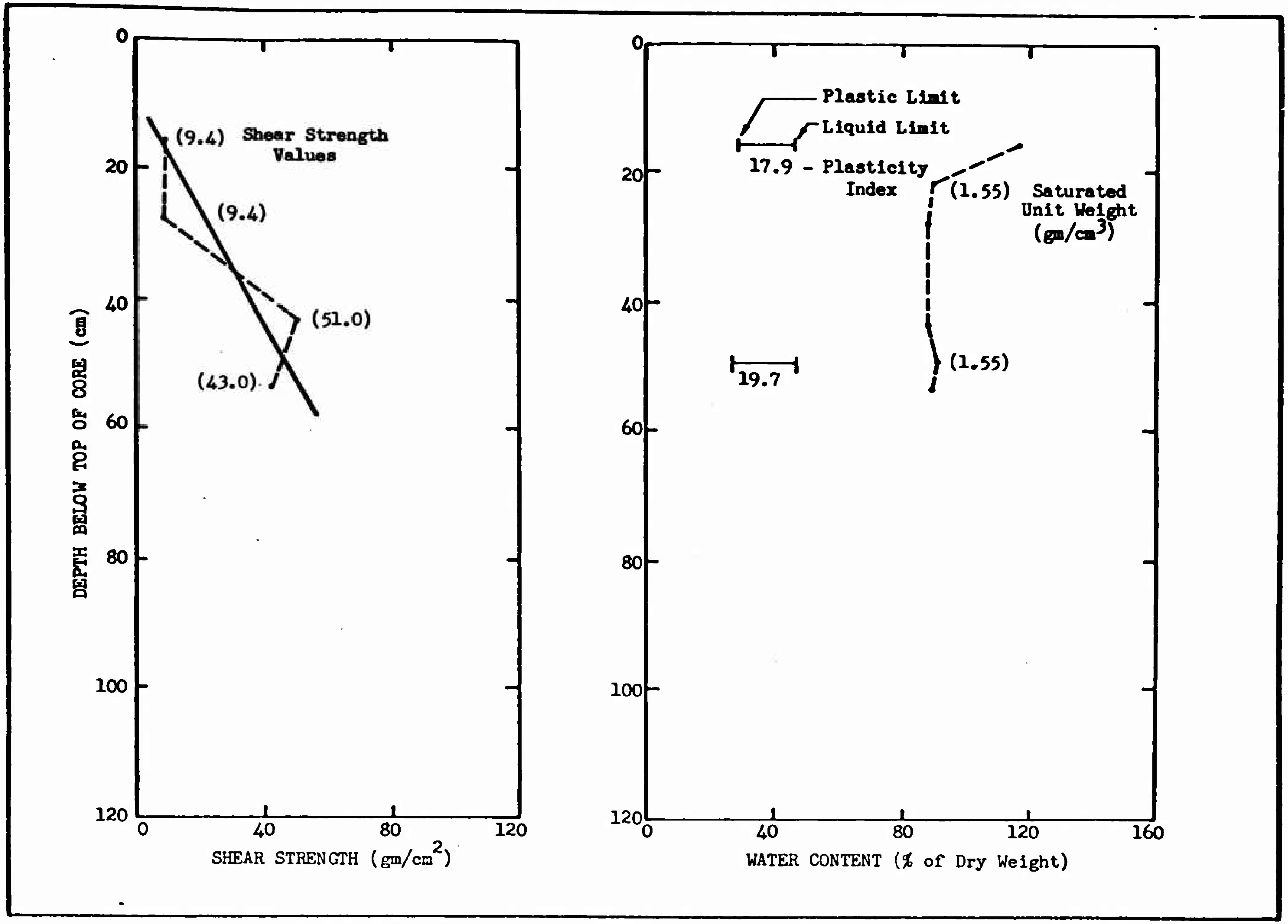



FIGURE 15. MASS PHYSICAL PROPERTIES AS MEASURED IN CORE 7.

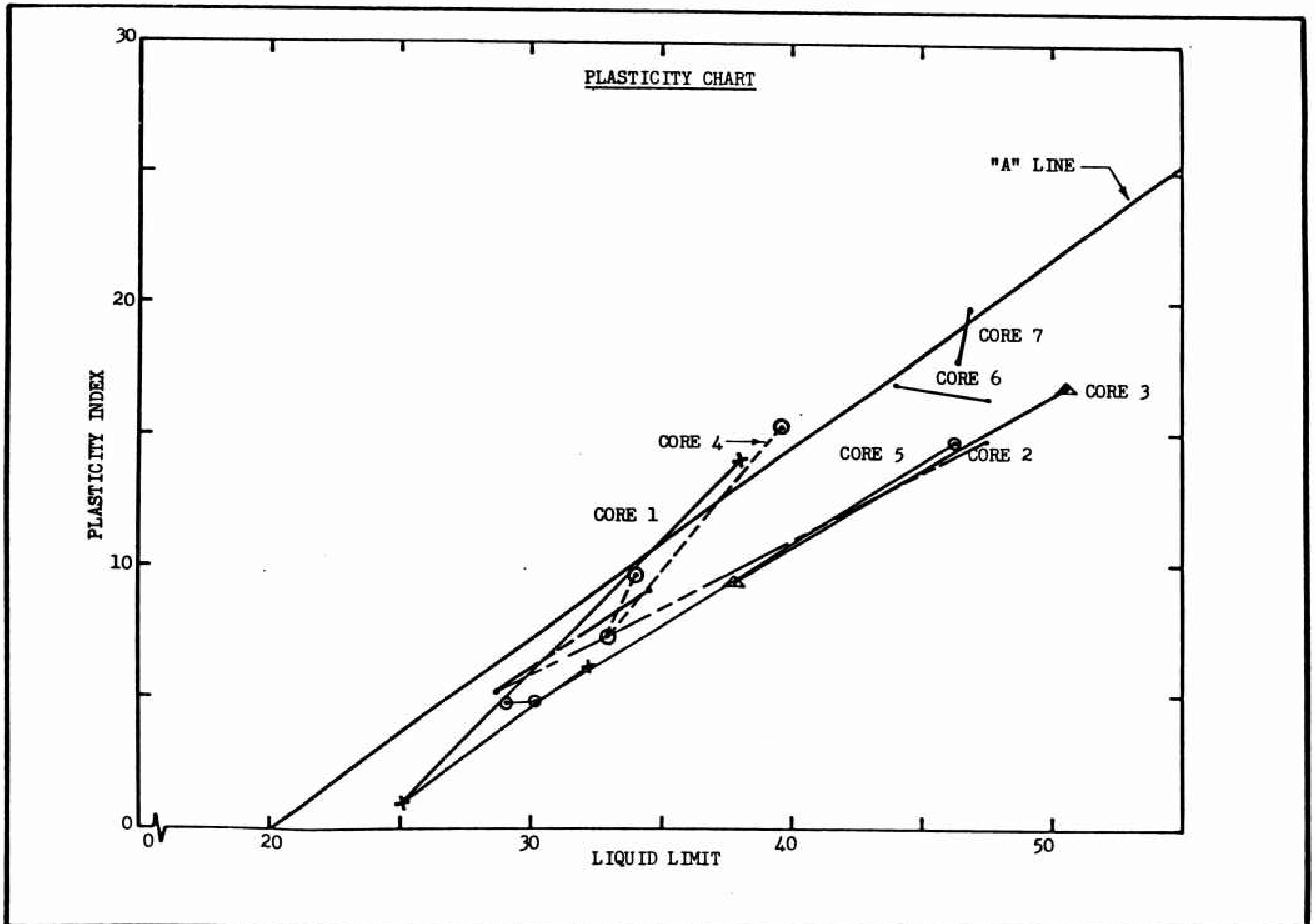



FIGURE 16. PLASTICITY CHART ILLUSTRATING THE RELATIONSHIPS BETWEEN THE MATERIALS IN EACH CORE AND THE "A" LINE.

in these cores is designated as inorganic silts and silty clays of low to medium plasticity (Casagrande, 1948). The cores previously obtained by Inderbitzen (1965) had the same designation on the plasticity chart.

Atterberg limits test results for the first four cores indicate that there is a general increase in both the plastic and liquid limits as one traverses from the sides of the gully to its center. This increase in values is most clearly shown in the tests conducted on the upper 15 to 20 cm of sediment in these cores. It is especially interesting that the change in values is best shown within the material that is virtually the same in grain size distribution through cores 1 to 3. At a given grain size the values of plastic limit and liquid limit depend on the mineralogical composition of the grains. (Terzaghi, 1955). The increase in values toward the center of the gully may well represent a mineralogical change within the material from interfluve to gully axis. These trends were not apparent in cores 5, 6 and 7 even though each core was taken progressively farther down a slope. Possible reason for these trends not to be present is the fact that the second transect was taken along a different topographical feature, an interfluvial slope.

## Activity

In conjunction with the Atterberg limits tests, activity ratios were computed for each sediment sample (Figs. 5 and 6). Activity ratio of a material is the ratio of the plasticity index to the percent clay size material (< 2 microns) and represents the surface activity of the clay fraction. According to Skempton (1953), the activity of a sediment is primarily dependent upon the mineralogical composition of the clay-size fraction. Based on the ratios computed, mica appears to be the predominate mineral constituent of the clay-size fraction. Other minerals present in the clay-size fraction are kaolinite, calcite and quartz. Activity ratio values do not indicate a

mineralogical change within the top lithologic unit of cores 1 through 3 as was suggested by the changes in Atterberg limit values. No trends were observed within the activity ratios which could be correlated directly to topography.

## Water Content

Water content determinations were made on all shear and bulk density test specimens. Results of these determinations are presented as percent dry weight on figures 9 through 15. Sediments collected during this study exhibit much higher water content values than the sediments collected during the 1965 study (Inderbitzen, 1965). Results obtained during the present work, however, agree better with measurements reported by Emery and Terry (1956), Richards (1962), Moore (1962) and Stiles (1967).

Of note is the observation that in all cores, except core 3, the water content value does not continue to decrease with core depth as generally reported. Instead, after a given core depth the water content remains fairly constant. Average value for the six cores where this situation is observed is 69 percent. This same trend was obtained in the cores of the 1965 study (Inderbitzen, 1965, p. 1321-1328). Furthermore, even though the 1965 cores had lower water content values in their upper sections than the latest cores collected, the constant water content value reached in these cores averaged about 60 percent, which is close to the results of the present study.

Despite the non-decreasing water content value with core depth, the shear strength continues to increase with core depth in six of the seven cores. Similar results were reported by Stiles (1967) for sediments from the Hatteras Abyssal Plain. This observation apparently indicates that the commonly

accepted inverse relationship between shear strength and water content does not necessarily hold true for all sediments. Very possibly it is not a simple direct relationship but rather an indirect relationship affected by other sediment properties (Inderbitzen, 1969).

A definite relationship between water content and the topography could not be determined as water content is a function of several factors including grain size distribution, porosity, and core depth. However, if water content values only within the surficial silty clay layer are considered, the effects of grain size distribution and depth within the core can be minimized. For cores 1 through 4, the water content values measured within the top 30 cm of core increase from the sides of the gully to the center. Within the top 50 cm of each core, the rate of water content decrease with depth in the sediment is highest on the gully sides and decreases toward the center of the gully. Cores 5, 6 and 7 exhibited a higher rate of water content decrease with depth than the first four cores. This suggests the possibility that the rate of water content decrease with depth in the sediment may be related to the physical slope angle of the sediments. However, more data is necessary before any relationship can be established.

## Bulk Density

Saturated unit weight, or bulk density, values for the sediments in each core are also listed on figures 9 through 15. Bulk density, like water content, is dependent on many factors including the lithology of the sediment and amount of consolidation the material has undergone. In order to minimize the effects of these factors, only bulk density values within the surficial lithologic unit have been examined for a relationship to topography.

Results indicate that the bulk density of the sediments decreases as one traverses from the sides of the gully to the center. The values obtained for cores 5, 6 and 7 down the interfluvial slope are also higher than those at the center of the gully. However, as with the water content and Atterberg limits values for these three cores, no particular trend is observed between the bulk density values and physiographic location.

## Shear Strength

Vane Shear Measurements - Vane shear strength test results are plotted as a function of depth within each core on figures 9 through 15. The solid line drawn among the plotted points represents the best-fit straight line determined by the least squares technique. Measured vane shear strengths were found to range from a low of 8.1 $gm/cm^2$ (core 3 at 30.5 cm) to a high of 89.9 $gm/cm^2$ (core 2 at 96.5 cm), with an average of 35.6 $gm/cm^2$ for the 33 samples tested. These vane shear strength values are much higher than those of the 1965 study where a range of 10.8 $gm/cm^2$ to 43.0 $gm/cm^2$ and an average of 18.0 $gm/cm^2$ was obtained for 24 samples. The differences in vane shear strength values between previously obtained cores and those used in the present study may be due to several factors including: higher percentages of sand in the 1965 cores, less disturbance to the latest cores, differences in location and distance between the 1965 and present coring sites.

The expected increase of strength with depth in each core is demonstrated by the fitted line; although the individual values are more erratic. The fluctuation of values may be partially due to the change in lithologic units within some of the cores. This is exemplified by cores 2, 4 and 5 where a decrease in strength is observed between the lower section of the surficial silty clay material and the upper portion of the next lower sediment unit.

If the best-fit line for cores 2, 6 and 7 is projected back to the abscissa (vane shear strength axis) a negative value is obtained for the surficial shear strength. This condition appears due to a non-linear strength increase with depth but the cause of the situation is unknown. The rapid increase of strength with depth does not appear due to a change in lithology as it primarily occurs in the cores that appear to contain all the same material, (cores 6 and 7). Nor does it appear due to excess consolidation of the lowermost sediments in the cores.

In order to determine if any excess consolidation was present within any of the cores, liquidity index tests were made throughout each core. If the liquidity index value is above 1.0 it indicates that the sediment has a water content greater than the liquid limit of the material, which usually denotes an unconsolidated state. A liquidity index value less than 1.0 indicates a water content close to the plastic limit and a compressed material (Wu, 1966, p. 15). Within all the cores, liquidity index values ranged from 3.23 to 7.23 indicating the absence of any pre-compression or excess consolidation. Nor were there any large decreases in index values within a single core as might be expected if the lowermost sediments had undergone excess consolidation.

A possible explanation for the existing situation is that the top 5 to 10 cm of each core was in a semi-liquid state and its shear strength could not be measured with the vane. Shear strength values would be very low within this section of core and the gradient of the strength versus depth line very steep. If the strength line for this section of the core could be plotted and joined with the existing line for shear strength values below 15 cm, a non-linear plot would be formed as shown by figure 17.

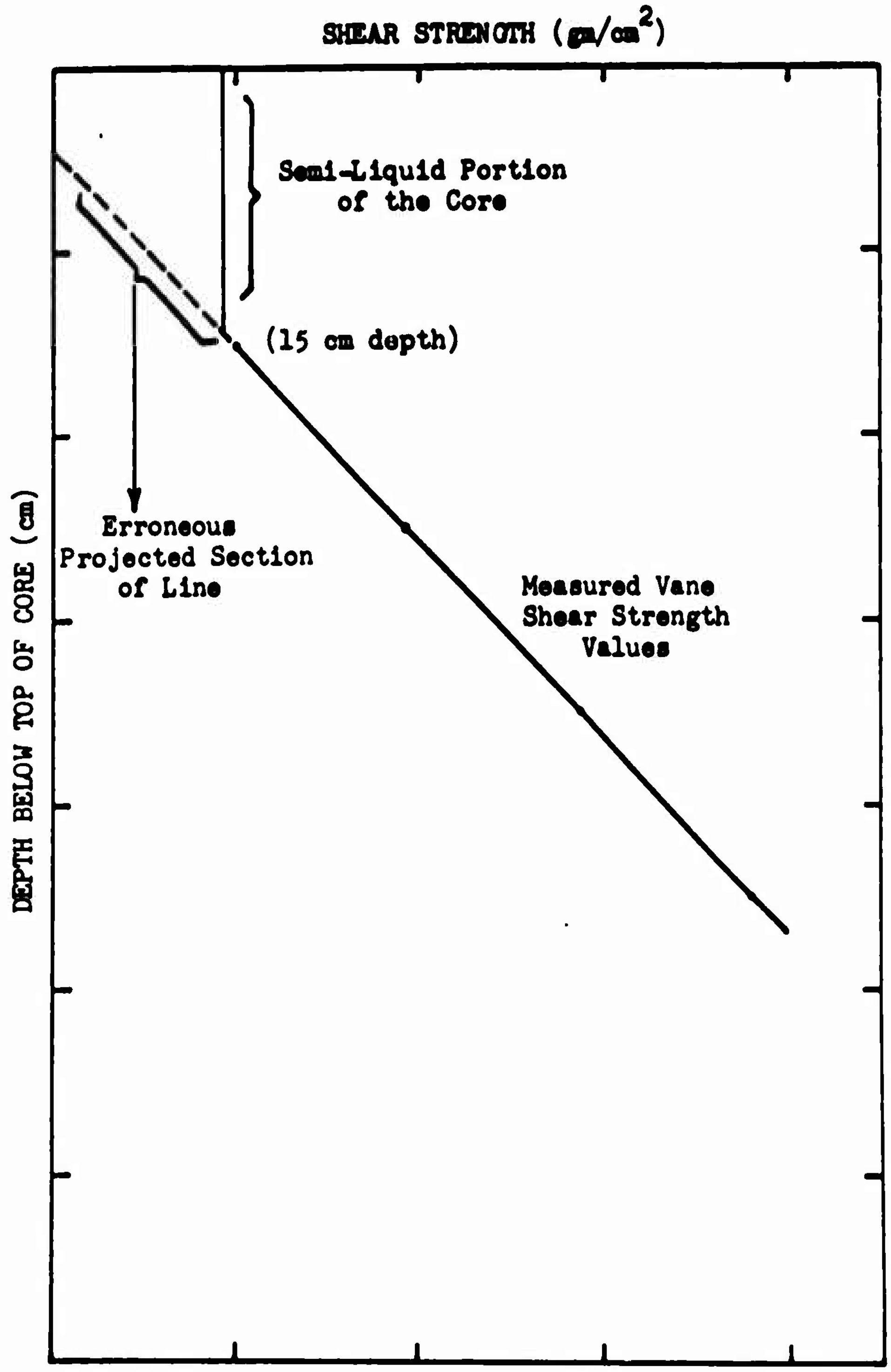



FIGURE 17. POSSIBLE EXPLANATION FOR VANE SHEAR STRENGTH VERSUS CORE DEPTH LINES IN CORES 2, 6 AND 7.

Attempts were made to relate the rate of shear strength increase with depth in the core to topography; however, no correlation was found. Efforts were also made to relate the individual vane shear strength values measured in the upper sections of each core to topography, however, this also proved unsuccessful. This does not rule out the possibility of a relationship existing between shear strength and topography but only shows the complexity of the shear strength variable. No other trends in the vane shear strength results were observed that could be related to the topography.

<u>Direct Shear Measurements</u> - Results of the direct shear tests are presented in the form of strength envelopes for each core (figures 18 and 19). Each envelope is based upon three direct shear tests made under different normal loads. The peak shear strength for each normal load, as determined by the test, is then plotted as a function of the load to form a strength envelope. The slope of the strength envelope represents the phi angle, or the angle of internal friction of the sediment and the intersect of the line on the ordinate axis denotes the cohesion value of the sediment. The direct shear strength envelopes reflect the strength characteristics of only a small core section. If the sediment type was similar throughout the core, the strength envelopes from the two series of direct shear tests made within each core agreed very closely and only one is shown (cores 6 and 7). However, if the direct shear tests were made in different sediment types, as was the case for the remaining cores, two distinctly different strength envelopes were obtained. A more detailed discussion of the shear strength results obtained by both direct shear and vane shear tests and their significance is given in Inderbitzen and Simpson (1969). This second report also gives a more detailed description of the testing procedures and methods used for determining the strength envelopes.

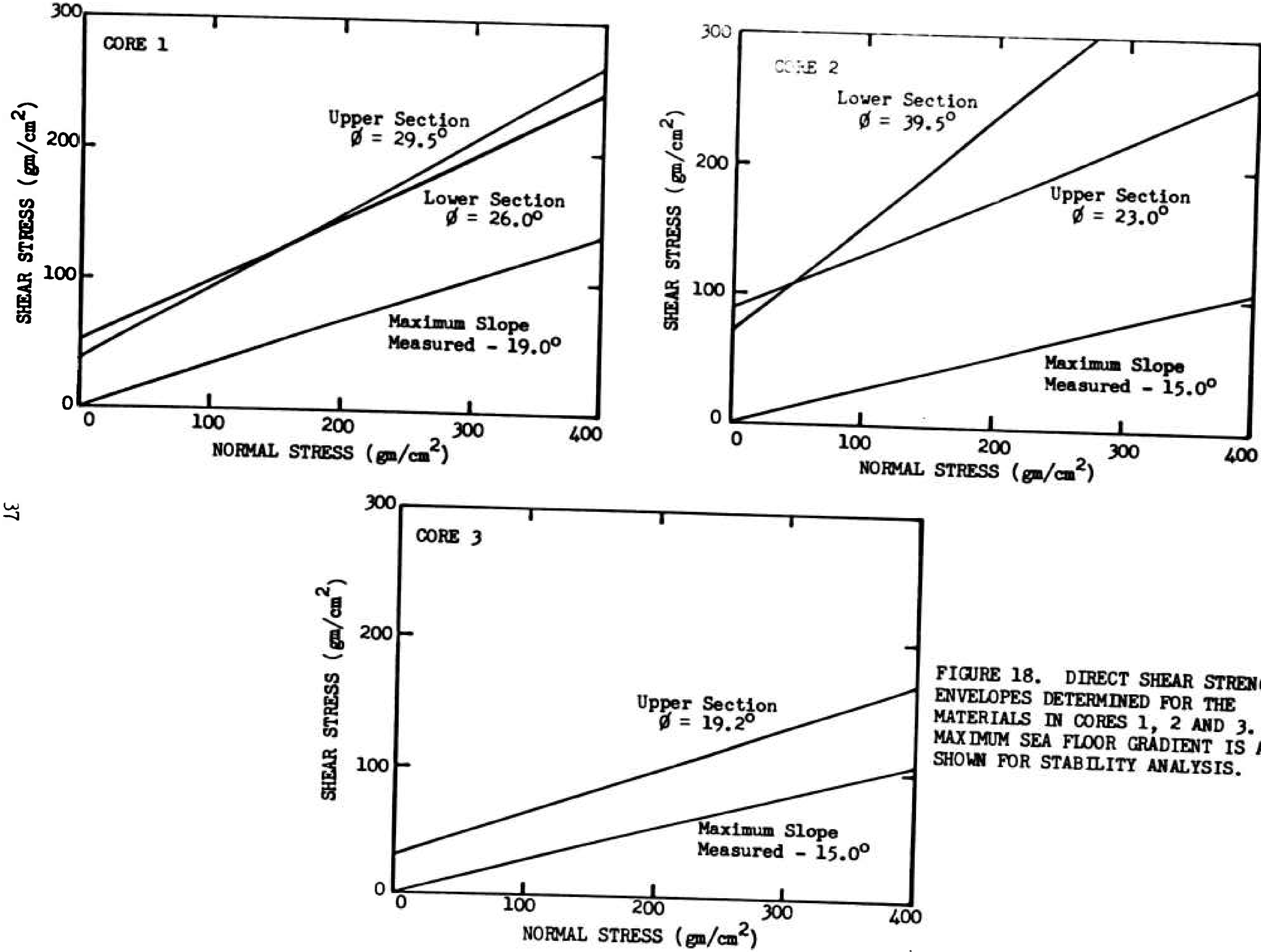



FIGURE 18. DIRECT SHEAR STRENGTH ENVELOPES DETERMINED FOR THE MATERIALS IN CORES 1, 2 AND 3. MAXIMUM SEA FLOOR GRADIENT IS ALSO SHOWN FOR STABILITY ANALYSIS.

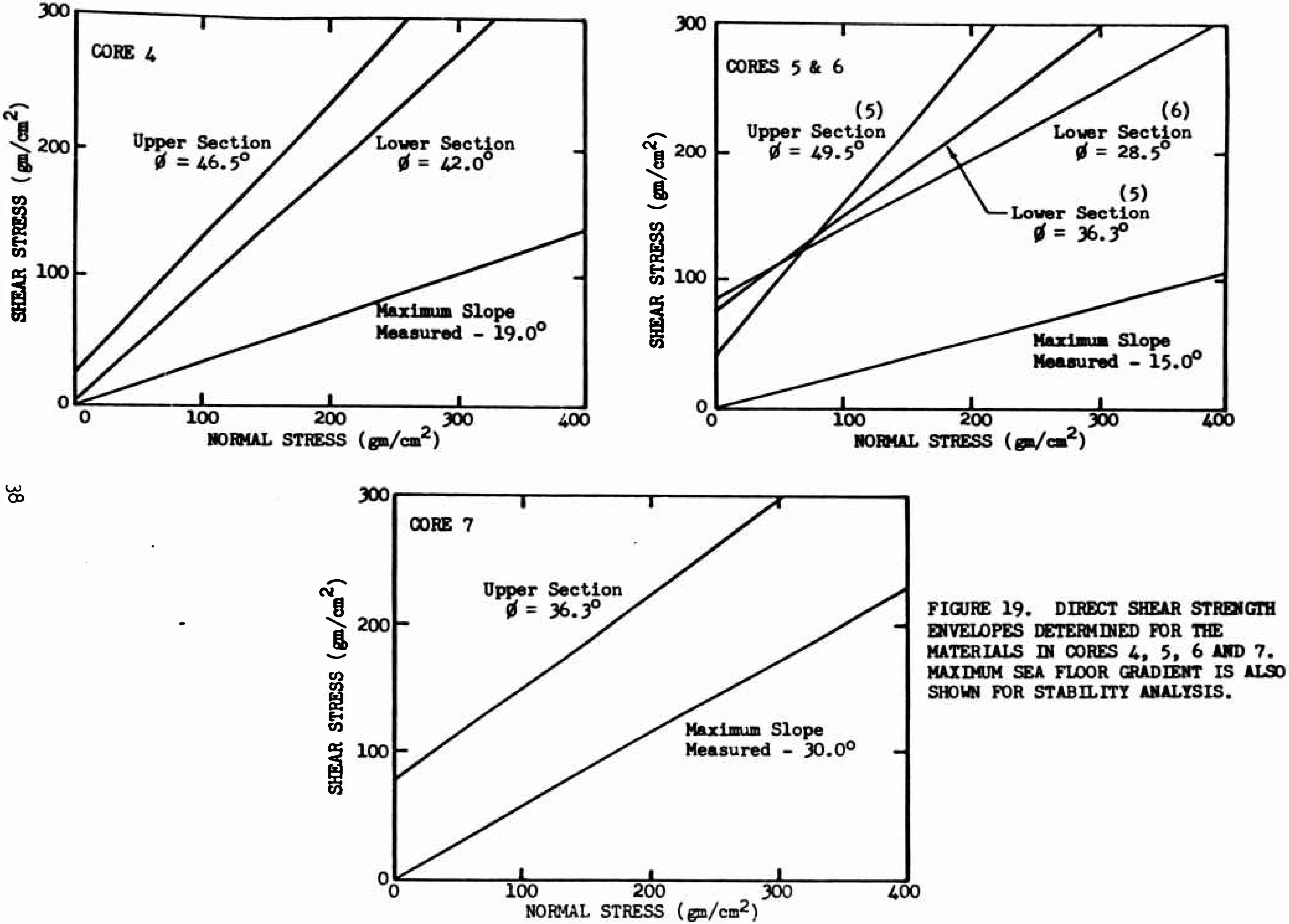



FIGURE 19. DIRECT SHEAR STRENGTH ENVELOPES DETERMINED FOR THE MATERIALS IN CORES 4, 5, 6 AND 7. MAXIMUM SEA FLOOR GRADIENT IS ALSO SHOWN FOR STABILITY ANALYSIS.

As with the vane shear strength results, efforts were made to establish trends in the direct shear test results that could be related to the topography. Attempts were made to correlate the slope of the strength envelopes for each core to their physiographic location with little success. Peak direct shear strength values obtained from the tests conducted at the same core depth were also investigated for relationships to topography. No relationship was apparent.

Unconfined Compressive Strength Measurements - Values for shear strength, as determined by unconfined compression tests, are shown as single points on figures 9 through 13. These points are plotted on the vane shear strength versus depth graph at the core depth of the test specimen. Generally, the shear strength values as determined by unconfined compression tests agree well with the best-fit line plotted for the vane shear strength values. This agreement indicates the expected similarity in shear strength values as determined by the two methods, at that depth in the core.

Because of the paucity of unconfined compression test values no correlation with topography was attempted. Since shear strength values as measured by unconfined compression tests are similar to values for the same depth as measured by vane, it is assumed that any relationship between shear strength as measured by unconfined compression tests and topography would be very similar to the relationship between vane shear strength and topography. No relationship could be determined between vane shear strength and topography. Therefore, it is assumed that there is probably no relationship between shear strength as measured by unconfined compression tests and topography.

## Slope Stability Analyses

Strength envelopes for each of the cores were determined from both vane shear and direct shear test results. These envelopes were then used to evaluate the stability of the underwater slopes (Figures 18, 19 and 20).

Procedure for obtaining the direct shear strength envelopes was mentioned earlier. Briefly, the procedure used to determine the vane shear strength envelopes is: select several shear strength values at various core depths from the least square line fit for each core; compute the effective normal load based on the weight of the overburden material and slope angle where the core was taken (see Taylor, 1948, p. 430); plot this normal load versus the particular shear strength value selected.

With the laboratory vane shear test, the test is actually performed with no vertical load on the sample. Yet the computed value for normal load due to overburden pressure at the core depth of the sample is assumed valid for determining a strength envelope. The samples tested appear to have been normally consolidated under their existing overburden pressures prior to removal of the core section and the vane shear test. Sections for testing are removed from the core immediately prior to the vane shear test which minimizes the time for any appreciable rebound of the grain structure. Since the actual normal load during the test can only be lower than the assumed load, any error in vane shear strength envelopes, calculated on the basis of assumed normal loads, will be conservative. In other words, if an error does exist, the slope (phi angle) of the calculated strength envelope will be less than the true strength envelope.

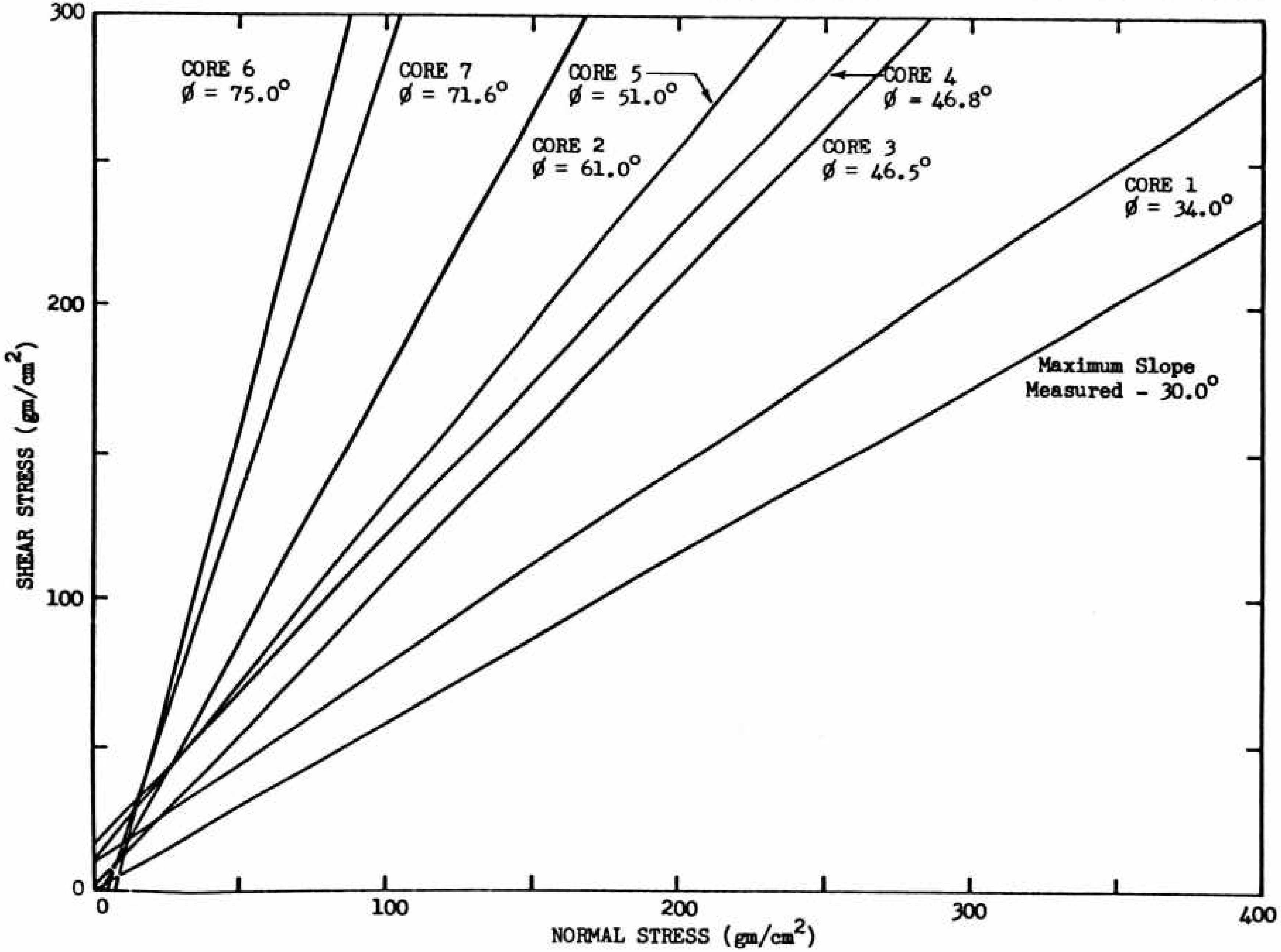



FIGURE 20. COMPARISON OF VANE SHEAR STRENGTH ENVELOPES FOR EACH CORE. MAXIMUM SEA FLOOR GRADIENT IS ALSO SHOWN FOR STABILITY ANALYSIS.

Stability of the sea floor slopes has been analyzed by the infinite slope theory described by Taylor (1948, p. 429). A detailed discussion on its application to the detection of unstable marine slopes using direct shear tests results is given by Moore (1961). The method itself is particularly applicable to those situations where the lateral distances of the slopes are much greater than the thickness of slumped section, and the basic force considered is that resulting from the overburden weight. The normal and shear stress components being easily derived if the angle of the inclined plane is known.

Accompanying the direct shear strength envelopes in each of the figures is a line drawn representing the sea floor slope angle observed at the location of the coring site. In the case of the vane shear strength envelopes only the maximum observed sea floor slope angle is shown since all of the strength envelopes are steeper. According to Taylor (1948), the point of intersection between the strength envelope and the line representing the sea floor slope angle determines the maximum thickness of sediment accumulation on that slope. At this intersection point the shear strength of the sediment equals the shear stress due to overburden weight. Any additional imposed load will cause a slope failure.

A comparison of strength envelopes as determined from both types of shear tests with the observed sea floor slopes indicates that the sediments in this area are stable despite the unusually high natural slopes present. Similar results were obtained by Moore (1961) and Buffington and Moore (1963) for cores from the San Diego Trough and sides of the Trough off San Diego.

Results of the stability analyses performed for this study are quite different from those reported by Inderbitzen (1965) for the cores obtained earlier in the immediate area. The six cores previously analyzed indicated that the sediments were unstable in their existing environment. Exact reason

or reasons for the opposite stability results of the present work are unknown but may include:

1) The present cores are far less disturbed and are more representative of true field conditions;
2) The gully and interfluvial slope where the present cores were obtained is not being subjected to the same geological processes as the shorter gullies to the north.

## SUMMARY

As stated in the preface, because of the paucity of data, no real conclusions can be drawn at this time, only apparent relationships indicated. Based upon analyses of the seven sediment cores the following relationships were observed.

1) There appears to be the same material within the top 20 to 25 cm of each core except one. Apparently this layer has been deposited since the formation of the gully.
2) Within this surficial layer of silty clay sediment the following topographical relationships are indicated. Traversing the gully from the lip toward the center,
   a) the amount of clay within the sediment increases,
   b) the liquid and plastic limit values increase,
   c) the water content of the sediment increases,
   d) the rate of water content reduction with core depth decrease, and,
   e) the bulk density of the sediment decreases.
3) No apparent relationships between topography and sediment properties are indicated for the cores obtained along the interfluvial slope.
4) Water content values appear to remain relatively constant below a certain depth in all the cores but one. The depth at which this occurs varies from 22 to 46 cm below the top of the core.
5) Except for the water content values within the surficial silty clay layer, there does not appear to be any relationship between water content and topography.

6) A non-linear increase in vane shear strength values is indicated for at least three of the cores. This phenomena may be due to the semi-liquid nature of the top several centimeters of core material.
7) No relationship between shear strength and topography is indicated.
8) Sediments encountered within all seven cores appear stable at the existing sea floor slopes where the cores were obtained.

To date, the work done on this project has demonstrated the great value of DEEP QUEST as a research tool. Without the submersible it would have been impossible to gain the fine resolution in topographic mapping necessary to detect the smaller gullies, or to obtain cores along precise transects. By the future use of DEEP QUEST to obtain cores, perform surveys and make in-situ measurements, the preliminary findings mentioned in this report will be verified. Further studies into the geomechanical properties of the sea floor can now be performed which were technically impossible before DEEP QUEST and its geological tools.

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